Imperfection-insensitive Continuous Tow Sheared cylinders

Geometric imperfection sensitivity is the largest influencing factor that limits the design of thin-walled monocoque cylinders. Current generation cylindrical architectures, such as those found in rocket launch vehicles, rely on the use of sandwich structures or blade-stiffened structures to reduce the imperfection sensitivity of the cylinder. Whilst must research has been focused on the creation of new knockdown factors that relate to the modern architectures used, this work focuses on reducing the imperfection sensitivity of a structure from a design perspective. Variable-angle composites offer an opportunity to tailor the load paths of structures, thus reducing the effective area over which imperfections initiate buckling. Continuous Tow Shearing (CTS) is one such variable-angle manufacturing technique. CTS does not cause common in-process manufacturing defects associated with Automated Fibre Placement such as fibre wrinkling or fibre buckling. In addition, CTS features a fibre angle-thickness coupling that results in a local thickness build-up, which, whilst increasing the mass of the structure, enables embedded stiffeners or hoops to be created by shearing the tow. This design feature is highly desirable in cylinders, as stiffeners are known to reduce the imperfection sensitivity of the structure. Here we show that the mass of a CTS cylinder is invariant of the number of embedded stringers or hoops created by the shearing process. Nonlinear finite element models with seeded imperfections are used to calculate a knockdown factor (KDF), a measure of imperfection sensitivity.

The CTS cylinders behaviour was measured using two criteria: KDF and imperfect, specific buckling load. Of the 2320 layups that were in the initial pool of possible architectures, 90 were considered for a nonlinear buckling analysis as they had a similar axial stiffness and compression buckling load to a QI cylinder on a mass-specific basis. Many cylinders were found to have a KDF 20 to 30% higher than a QI cylinder. It was found that, in general, the fewer the number times the lamina was sheared, the higher the KDF. However, it was found that the higher the number of stiffening elements, the higher the specific, imperfect buckling load. The stiffening elements did not act as panel breakers as the EI contribution was not large enough, instead acting as load attractors. Layups that used the maximum amount (70 degrees) of shearing had a lower KDF when compared to a layup that used a medium degree (30 – 40 degrees) of shearing. The cylinders that had the highest KDF had a localised buckling mode, indicating that the shearing had caused a trapping of the buckling mode. The cylinders that had the lowest KDF had a global buckling mode. It was found that there is a relationship between the difference in pre-buckling strain field (between a perfect and imperfect cylinder) and the knockdown factor. This novel relationship is strong when the KDF is high, showing that a linear analysis can provide a first-order approximation of the imperfection sensitivity of a cylinder.